Advances in Furnace Control

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Abstract

Since the first INFACON was held in 1974, the ferro-alloy industry has experienced a period of tremendous growth. Bigger furnaces, new processes, faster computers and an increasingly competitive market have necessitated control of all aspects of the production process. What has been achieved over the past 24 years? The authors present a personal view of past and present developments.

Introduction

When the first INFACON was held in Johannesburg in 1974, the ferro-alloy industry was going through a period of tremendous growth worldwide and especially in South Africa. This growth was triggered by a buoyant world economy and the new steelmaking processes which could accommodate higher carbon levels in the ferro-alloys. Although much research was being done in South Africa to categorize local ores and understand the process fundamentals, little work was being done on furnace control as such. Union Carbide (USA) and Elkem (Norway) were the leaders in computer control of furnaces. Union Carbide, with their experience in control of chemical processes, had implemented computer control on their carbide furnaces by the late 1960s. Elkem started a little later, but had implemented and were prepared to market the technology for controlling ferromanganese and ferrosilicon furnaces by 1974.

Although they were not fully appreciated then, Arnesen and Asphaug[1] encapsulated the problems of controlling the processes for ferro-alloy production. These were:
1. long time lags conducive to unstable processes
2. problems with direct process measurements

To this list, we add a few of our own:
3. problems with computers
4. problems with raw materials
5. problems from financially-imposed constraints.

These last three have become apparent only in later years, but they appear to be here to stay.

This paper will follow the some of the developments in the furnace control from that first INFACON to the present conference.

Furnace Control in 1974

Traditionally, there are three types of control structure that are commonly used in ferro-alloy furnace control:
1. Feedback - process outputs are measured and then the inputs are manipulated in an attempt to control these outputs, in order to achieve some control objective.
2. Inferential - available outputs are measured to infer the values of unmeasured variables, and these inferred values are used to manipulate the inputs.
3. Feedforward - disturbances are measured directly and the inputs are adjusted in an attempt to compensate for the expected effects on the outputs.

If the time delay of the output or input measurement is more than about 20% of the time constant of the process, there will be difficulty in controlling that output using traditional feedforward or feedback techniques. In a submerged-arc furnace, the feed system and the analysis of the product normally introduces delays of a couple of hours, i.e. comparable to the time constants of the process, and this means that difficulties in the control of the furnace must be expected.

There are a number of measurements that have been used, and continue to be used, to control furnaces. These are:

Continuous measurements	Discontinuous measurements
Primary electrical measurements	*Raw material weights*
Secondary electrical measurements	*Raw material analyses*
Gas flow rate	*Metal and slag analyses*
Gas temperature	*Tapped metal mass*
Gas analysis	

Traditionally, what the engineer would try to control is metal specification, metal production and furnace efficiency. However, the accountant knows that costs and market share really need to be controlled, and these can and will introduce disturbances that the engineer's control scheme (and blood pressure) will have difficulties handling.

Both Elkem and Union Carbide[2] extensively developed their control systems during the 1970s and this development was facilitated by the advent of mini-computers. These computers allowed engineers to develop and implement control systems at a reasonable cost (for those days) and within a reasonable time frame. The functionality and objectives of these control schemes were similar and were:

1. power input and electrode regulation
2. electrode slipping based on baking and consumption
3. control of raw-material batching, based on feed and product analyses and product specifications
4. carbon control based on inferential measurements.

In addition, the computer provided logging and reporting functions and improved operator communications. The consensus was that these systems increased production, improved efficiency, decreased process variability and paid for themselves.

Developments in Computer Control at Mintek

At that time both Elkem's and Union Carbide's commercially-available systems had been specifically developed for ferrosilicon and ferromanganese. In South Africa, however, with its abundant reserves of chromite ore, there was also a major emphasis on ferrochromium. In particular, there had been problems controlling a new 48 MVA ferrochrome furnace. This furnace was the among the first of many large furnaces that had been built for ferro-alloy production. In a collaborative effort with Samancor, Mintek installed an online mini-computer system on this furnace, and proceeded to develop a similar control system. The results were impressive and were reported[3] at INFACON 80.

However, this development differed significantly from the other control systems, in that it was done on a large ferrochromium furnace. For one thing, bigger furnaces have bigger electrodes to carry more current at lower resistances and lower power factor than previously. One of the consequences of operating at low power factor is increased interaction between the electrode currents, leading to control problems[4]. The solution is to base electrode regulation on resistance, which will de-couple the interaction between electrodes. Although the resistance can be measured on the secondary side of the transformers, we found it impossible to maintain accurate electrical measurements on these larger furnaces. The solution was to calculate the secondary resistances from the primary electrical measurements, and regulate the electrodes using these values. This has proved to be a very successful[5] control technique, which has since been applied commercially to many different processes.

Another side to this development work was the introduction of microprocessors. These were used both for improving the accuracy of the existing analogue weighing system and for providing the processing power of the prototype electrode controller. These microprocessors were made by a then little-known company called Intel. These microprocessors required a specialist to program them, but they worked reliably in a hostile environment and needed no further attention. The same could not be said about the mini-computer system. It need an air-conditioned environment, a good earth, a motor generator set, and considerable attention - very similar to networked PC systems of today.

Developments in Ferrochromium Production and Control

The 1970s heralded a period of tremendous development and growth in the ferro-alloy industry. In particular, the Japanese were developing an integrated and efficient ferro-alloy industry to support their steel industry. However, they were dependent on the supply of raw materials and energy from outside the country. Already in 1973 the price of oil had undergone its dramatic rise, thereby increasing the price of electricity and everything else with it. As energy is one of the main components in the cost of ferro-alloy production, ways of utilizing cheaper energy alternatives were and are still being sought. A particularly good example at that time was the Showa Denko process, which pre-reduced the chromite in a rotary kiln, thus greatly reducing the electricity requirements of the process. Although it had a high initial capital expenditure, this was an elegant and efficient process. However, from a control point of view, there were two unit processes with long time lags. Thus the operation required good feedforward control with a homogeneous and carefully monitored feed material.

In contrast to the Showa Denko process, Union Carbide built a new plant in South Africa designed to cope with a large percentage of fine chromite ore. South African chromites tend to be extremely friable, and so by the time they get to being consumed in the furnace there is usually a large percentage of fines. Use of fine chromite ore makes no operational sense, but it must make economic sense as this is the way the majority of new ferrochromium furnaces have since gone. Ideally, one would like to get the right balance between ores, fluxes, reductants and energy requirements to achieve optimum reducing conditions. Even the most carefully weighed out material mix goes a long tortuous route before reaching the reaction zone beneath the electrodes. Only if there are materials of similar size and density, can the segregation be kept to a minimum. A feed consisting of heavy fine ores and light reductants is a recipe for segregation and instability.

One of the consequences of operating with a high percentage of fines is that the furnace resistivity can change dramatically in a short time. This can lead to an unbalanced electrical situation, where the electrodes may either climb out of the furnace or lose load completely. As electrode penetration needs to be maintained, some compromise between penetration and power input must be achieved. Although tapping the transformers differentially is a compensation technique that is widely used, it actually accentuates the imbalance in power, and can easily lead to over-stressing of the transformers. Mintek has developed a form of feedback control to limit the movement of electrodes where applicable. Neither option will solve the basic problem of less than optimal reducing conditions, which is essentially a metallurgical problem and not an electrical one. Each plant usually has its own particular remedy to handle what is basically an unstable situation.

A more efficient way to handle the fine ore is to feed it together with fine reductant directly into the arc zone at a rate determined by the energy requirements of the process. This is precisely what was achieved using the DC arc smelting technique developed by Mintek and Samancor. Alternatively, the fines can be briquetted or pelletized which will ensure a more homogeneous furnace feed, and less segregation.

The carbon monoxide produced in the reduction furnace is a major source of energy. The gas will burn on the surface of the bed in an open furnace, which will provide for partial preheating of the feed materials. The more efficient solution is to capture the gas for pre-heating, pre-reduction or electricity generation, but this is difficult if the process is inherently fluctuating because of the use of fines.

Process or Economic Optimization

Today, the overriding consideration in industry is the cost of production. If electricity is expensive, options may be to build a power plant or use pre-heating or pre-reduction. If lumpy ore is expensive, then fine ore may have to be used, which may or may not have to be briquetted or pelletized. If coke or charcoal is expensive, then coal or char may have to be used. So, even though control is important, it too has to be cost-effective. After the electricity, the raw materials, the personnel, the furnace transformers, the gas cleaning plant, etc., have all been paid for, can the money be justified to pay for a computer control system as well?

By 1986, Elkem[6] were reporting "Of even greater economic impact than process control are metallurgical decisions about raw materials, set points for control loops, scheduling of preventative maintenance and other management considerations". Thus today's process control system must also generate the numbers that permit the process performance to be scrutinized closely. In an increasingly competitive market, the successful producer has to supply a quality product at a price that the market demands and still make a profit. For some producers, this has meant continually changing the type, grade, size and quality of their feed materials to produce different products with different specifications cheaper than the opposition. In such circumstances the producer not only needs a good basic control system - he also needs to be able to monitor everything that was going on and keep the information for future reference. He needs to be able to categorize which mix of materials could produce a particular product cheaply and efficiently[7]. The metallurgist needs to deliver the product on time and within budget, but at least he can have a sophisticated computer infrastructure/information system at his disposal to help him[8].

Computer Hardware and Software for Control and Optimization

The power/price combination of present-day hardware and software may entice the unwary into believing anything is possible. Glossy brochures promise seamless integration, system integrity, gateways to the world, and almost control of one's own destiny! Every few months, new hardware will generate new software, which will generate new solutions and create more problems. Even more rapidly than the mini-computers of old, present-day hardware and software become obsolete and difficult to maintain. But, even if one can afford to throw the hardware out, the man-years of development in software needs to be preserved and re-used. This has never been an easy task. Before climbing on the upgrade treadmill, the end user needs to ask himself some old-fashioned questions like:

- what are the objectives, functional requirements, manpower requirements, and maintenance requirements,
- how will it integrate into our existing infrastructure,
- how much training do the staff need, and
- what will it really do for me?

Advances in Furnace Control?

So, how far have we advanced since the first INFACON?

1. Feedback - there have been few (no?) new direct process measurements since our traditional list more than 20 years ago.
2. Inferential - there have been some (one?) new measurements on silicon processes[9], and many attempts to measure or estimate electrode length. There have been a number of advanced models and techniques applied to the silicon production process to control the carbon balance and optimize performance (INFACON 95).
3. Feedforward - the number of different types of feed materials have necessitated more sophisticated classification and regression techniques (e.g. neural nets) to control the product, optimize production and reduce costs.

Expert system control has been (or has been claimed to have been) applied to some or all of the above. There is no doubt, it will have an increasingly important role to play, but like the new software systems, the user needs a clear idea of what he wants to do and how he intends to do it.

Acknowledgment

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